Solubility

**Teacher Background:** Solubility appears in many state standards and is a key concept for students to understand. Many labs similar to the one located here use soluble ionic solids, such as nitrate salts. The disposal of these compounds have a negative impact on an aquatic environment. Introduction of a nitrate into an ecosystem causes a spike in algal growth and a ripple effect is felt up the food chain, or in worse case scenario eutrophication can occur.

Solubility can also be used to discuss the hazards of certain forms of chemical substances and can also help students understand solubility rules. The example of barium is a useful one and this lab can be used to discuss how different forms of an element (i.e., barium) can be toxic, while other forms can be non-toxic to humans. Soluble barium compounds are toxic to humans (chloride, nitrate and carbonate salts), while insoluble barium compounds can be very useful for medical applications. Barium sulfate is ingested by patients before they undergo x-ray imagine for diagnostic procedures. The barium can be used to observe the GI tract, for example, in these procedures because barium absorbs x-rays more strongly than other compounds.

**Objective:** To qualitatively and quantitatively describe the relationship between temperature and solubility for gases and solids. To understand solubility rules.

**Learning Outcomes:** Students will...
- Recognize the relationship between temperature and solubility of solids and gases
- Produce a graphical representation of the relationship between a change in temperature and concentration of a solid.
- Understand solubility rules
- Understand how solubility can be used to predict toxicity of some chemicals

**Time:** 2 x 45-60 minute class periods

**Materials:**
**Part 1** (teacher demo)
- 2 x 400 ml beakers
- 3 x 100 ml graduated cylinders (one with poked hole in it so that students can see that it is not just a liquid leaking out of the carbonated beverage)
- 2 x alcohol thermometers
- 1 x hot plate
- 4 x parafilm pieces (2 in. x 2 in. pieces)
- Scissors
- Clear Carbonated Beverage
- Ice

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**Part 2** (student lab)
- Magnesium Chloride Hexahydrate (MgCl₂•6H₂O, MW = 203.31 g/mol)
- Magnesium Sulfate Heptahydrate (Epsom salt) (MgSO₄•7H₂O, MW = 246.47 g/mol)
- Alcohol Thermometers
- Hot plate
- Stirring rod
- Balance
- Scoopula
- 8 aluminum weigh pans
- 2 x 150 ml beakers
- 100 ml graduated cylinder
- Water

**Procedure (Part 1):**
- Explain to students that you will show them through a demo the relationship between solubility and gas mixtures.
- Ask students to record their observations on Part 1 of the observation sheet (handout attached).

**Demo:**
1. Prepare ice bath by placing ice into one 400 ml beaker until it reaches the 150 ml line. Add water to the 150 ml line in the same beaker. Record the temperature of the ice bath after allowing the temperature to equilibrate for 5 minutes.
2. Add water to the other 400 ml beaker until it reaches the 150 ml line. Heat this beaker on a hot plate until it reaches 80°C. Record temperature of the hot water bath after 5 minutes of heating.
3. Pour the clear carbonate beverage into each of the 100 ml graduated cylinders until it reaches the top brim (more than 100 ml added to each one).
4. Tightly seal each graduated cylinder using 2 pieces of parafilm per cylinder.
5. Slowly invert each cylinder and check for leaks. If leaking occurs, re-wrap the parafilm until a tight, leak-free seal is obtained.
6. Using the tip of one scissor blade, poke a hole into the top of the cylinder’s parafilm seal. Repeat for the other cylinder, making sure that the holes for each cylinder are equal in size.
7. Simultaneously invert cylinder #1 in the 400 ml beaker ice bath and cylinder #2 in a 400 ml beaker hot water bath. Allow the cylinders to sit inverted in the beakers for 5 minutes.
8. Ask students to note the starting volume and ending volume of liquid in 400 ml beakers. Students should make observations and answer questions on the student data sheet.
9. Group students into lab groups of 2-3 for Part 2 of the experiment
10. Hand out the students’ sheet and ask students to follow the directions and complete the lab.
Procedure and Notes (Part 2):
- Discuss solubility rules of ionic solids.
- Discuss how different forms of certain elements have different solubilities.
- Hand out Student Worksheets, Part 2
- Allow students to perform the procedure outlined in Part 2 and record their results on the student worksheet tables.
- After they perform the procedure, allow the pans to dry in either a drying oven (set at 80-100°C) for one hour, or allow them to sit overnight in a safe location to evaporate the water. Note: If you are allowing them to dry on their own, the magnesium chloride samples might not dry since magnesium chloride is so water soluble. If you do not have a drying oven, then you can alternatively gently heat the samples on a hot plate to dry off the water. Be careful when doing this – do not heat too high or too fast (keep the hotplate around 80°C).
- They should find that the chloride salt of magnesium is more soluble than the sulfate salt. Once they come to this conclusion, you may use the supplemental information sheet about barium compounds. Ask them to read and relate their findings to the case of barium.
Fill out the data below, and answer the questions based on your observations.

**Cylinder #1 – in ice water bath**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature of ice water bath °C</td>
<td></td>
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<tr>
<td>Initial volume of gas ml</td>
<td></td>
</tr>
<tr>
<td>Final volume of gas ml</td>
<td></td>
</tr>
<tr>
<td>Initial volume in beaker ml</td>
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</tr>
<tr>
<td>Final volume in beaker ml</td>
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</tr>
</tbody>
</table>

**Cylinder #2 – in hot water bath**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature of hot water bath °C</td>
<td></td>
</tr>
<tr>
<td>Initial volume of gas ml</td>
<td></td>
</tr>
<tr>
<td>Final volume of gas ml</td>
<td></td>
</tr>
<tr>
<td>Initial volume in beaker ml</td>
<td></td>
</tr>
<tr>
<td>Final volume in beaker ml</td>
<td></td>
</tr>
</tbody>
</table>

**Observations:**

1. Which cylinder had its liquid volume decrease faster?

2. As the liquid in the cylinders decrease, does the volume of the gas increase or decrease?

3. After 30 seconds, which cylinder has the most bubbling?

4. After 2 minutes, is there any bubbling of gas in cylinder #1 (ice water bath)?

5. After 2 minutes, is there any bubbling of gas in cylinder #2 (hot water bath)?
Solubility
Student Worksheet
Part 2: Solubility of solids

Materials:
- Magnesium Chloride
- Magnesium Sulfate
- Alcohol Thermometers
- Hot plate
- Stirring rod
- Balance
- Scoopula
- Weigh boats
- Aluminum weight pans (8)
- 2 x 150 ml beakers
- 10 ml graduated cylinder
- Pipette (autopipette or graduated pipette) and pipette tips
- Water

Procedure:
1. Weigh out 25 grams of magnesium chloride and put it in one of the 150 mL beakers. Label the beaker MgCl₂.
2. Measure 12.5 mLs of water in to the beaker and stir until all of the MgCl₂ dissolves.
3. Weigh out 25 grams of magnesium sulfate and put it in the second 150 mL beakers. Label the beaker MgSO₄.
4. Measure 25 mLs of water in to the beaker and stir until all of the MgSO₄ dissolves.
5. Measure the temperature of both solutions. Record your results.
6. Prepare aluminum weigh pans numbered 1 through 8.
7. Weigh the aluminum pans and record the weight of the empty pans in the table.
8. Place both beakers on the hot plate. Heat the solutions to raise the temperature to 30°C. Gently stir the solution occasionally as the temperature goes up (allow any solids to settle before taking the 1 mL sample as explained in step #9).
9. At 30°C, remove 1 mL of solution from the MgCl₂ solution and place it in the beaker labeled #1. Record the mass of the aluminum pan with the 1 mL of solution.
10. Repeat step #9 for the MgSO₄ solution, but place the 1 mL solution in pan #5. Weigh the pan with the solution in it, record the weight in the table.
11. Heat both solutions to 40°C and again remove 1 mL of solution and place the solution in pans #2 (MgCl₂) and pans #6 (MgSO₄). Record the weights of the pans and solutions in the table. Remember to gently stir the solutions as the temperature increases and allow any solid to settle before removing a sample of the liquid.
12. Repeat step #11, bringing the solution temperatures to 50°C.
13. Place all 8 pans in drying oven, or in a location to allow to dry overnight.
14. The next day (or next lab session), record the weight of the pans after they are dry.
Solubility
Student Worksheet
Part 2: Solubility of solids

Record your observations below:

Weight of MgCl₂: ________ grams      Water added to MgCl₂: ________ mLs

Weight of MgSO₄: ________ grams      Water added to MgSO₄: ________ mLs

<table>
<thead>
<tr>
<th>Pan #</th>
<th>Solid</th>
<th>Empty pan weight (g):</th>
<th>Pan weight with liquid (g):</th>
<th>Temperature of sample taken (°C):</th>
<th>Pan weight after drying (g):</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MgCl₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>MgCl₂</td>
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<td>3</td>
<td>MgCl₂</td>
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<td>4</td>
<td>MgCl₂</td>
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<td>5</td>
<td>MgSO₄</td>
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<td>MgSO₄</td>
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<td>MgSO₄</td>
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<tr>
<td>8</td>
<td>MgSO₄</td>
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</table>
Use the table below to calculate the concentration of each sample that you took from both solutions.

<table>
<thead>
<tr>
<th>Pan #</th>
<th>Solid</th>
<th>Weight of solid left after drying:</th>
<th>Weight of water in sample (before drying):</th>
<th>Concentration of sample (g/mL)*:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MgCl₂</td>
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<tr>
<td>2</td>
<td>MgCl₂</td>
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<tr>
<td>3</td>
<td>MgCl₂</td>
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<td>4</td>
<td>MgCl₂</td>
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<td>MgSO₄</td>
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<td>MgSO₄</td>
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<td>8</td>
<td>MgSO₄</td>
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*Assume 1 mL of water = 1 gram of water
Lab Questions
Part 1

1. Which cylinder collected more gas?

2. What is happening to the gas in cylinder #2 (in hot water bath)? What affect does it have on the liquid’s containment inside the cylinder?

3. Why is there more volume in the hot water beaker than in the ice water beaker at the end of the experiment?

4. Does more gas escape when it is warmer or cooler?

5. When gas escapes from the liquid, is it because it is more or less soluble in the liquid?

6. Is the gas more soluble at higher or lower temperatures?

7. When gas escapes from a carbonated beverage, what affect does it have on the taste of the beverage?

8. Name the gas present in the carbonated beverage that is responsible for its fizz.

9. Which would you rather drink, hot pop or cold pop? Explain your reasoning using the principles from this lab.
Part 2

1. Using excel, or graph paper, plot the concentration of MgCl₂ versus the temperature. Plot the concentration of MgSO₄ versus temperature on the same graph. Be sure to place the independent and dependent variables on the appropriate axes, and include labels, units and a title.

2. Based on the graph, how many grams of MgSO₄ will dissolve in 100 mL of water at 70°C?

3. Describe the difference between the solubility of gases versus solids with a change in temperature.

4. Write a sentence to answer the question: What is the relationship between the solubility of magnesium chloride and the temperature of its solution?

5. How do your results help you to predict the solubility of barium chloride and barium sulfate? Which one would you expect to be more soluble?

6. Discuss the importance of understanding solubility and how solubility relates to the toxicity of certain chemicals.